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A 1055 FT/SEC IMPACT TEST OF A TWO FOOT DIAMETER MODEL NUCLEAR REACTOR CONTAINMENT SYSTEM WITHOUT FRACTURE

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ABSTRACT

An impact test was conducted on a 1119 pound - 2 foot diameter sphere model at the Holloman Sled Track in Alamogordo, New Mexico. This test is part of a study to determine the feasibility of containing the fission products of a mobile reactor in the event of an impact. The model simulated the reactor core, energy absorbing gamma shielding, neutron shielding and the containment vessel. It was impacted against an 18,000 pound reinforced concrete block at 1055 ft/sec. The model was significantly deformed and the concrete block demolished. No leaks were detected nor were any cracks observed in the model after impact.

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SUMMARY

Future applications of nuclear energy may require the use of a mobile nuclear reactor. Fission products in mobile reactors must be contained with the same level of confidence as in stationary powerplants. One method for containing fission products in the event of an impact of a mobile reactor is to put the reactor in a containment vessel and design the containment vessel and its contents to absorb the impact energy without rupturing the containment vessel.

A previous set of five tests was conducted at Sandia Corporation on two-foot diameter mock-up models of a reactor containment vessel system. The models weighed from 350 to 1305 pounds. They were impacted at speeds from 241 to 580 feet per second. No leaks were detected nor cracks observed on any of the models after impact. Examination of the models indicated a potential for survival at impact speeds of 1000 feet per second.

A new series of tests were then planned with impact velocities up to 1000 ft/sec. The first test model of this series was impacted at 640 ft/sec. This report describes another test conducted at 1055 ft/sec impacting against an 18,000 pound reinforced concrete block. The model weighed 1119 pounds. It simulated the reactor core, energy absorbing gamma shielding, neutron shielding and the containment vessel.

Observations made from the results of this test included

(1) No leaks were detected nor cracks observed on the model.

(2) The concrete block, was totally destroyed at impact.

(3) There was no rebound velocity observed when the model impacted the concrete block.

(4) The maximum diametral increase measured on the model was 21 percent.

(5) The deformation δ/R was measured as 0.91 (where δ is defined as the diameter of the vessel before impact minus the height of the vessel after impact and R is the vessel radius before impact).

INTRODUCTION

In all mobile nuclear reactors, fission products must be contained with the same level of confidence as in stationary power plants. In the case of a high speed mobile reactor, such as a nuclear airplane, impact velocities of 800 to 1000 ft/sec can occur.

One method for containing fission products under these severe conditions is to put the reactor in a containment vessel and design the vessel and its contents to absorb the impact energy without rupturing the containment vessel. The energy of impact would be absorbed by deformation of the containment vessel and the internal components of the vessel such as the shielding and reactor parts.

Initially, experimental deformation data was correlated by Morris on 3/4 inch to 4 inch i.d. hollow vessels (refs. 1 and 2) which had been impact tested to 700 ft/sec as part of an isotope space program (ref. 3). His correlation predicted that a large reactor containment vessel would deform similar to the small vessels. The correlation, however did not consider the effects of internal components. Tests were necessary to correlate these effects.

Five two foot diameter mock-up models of reactor containment vessel system were tested (refs. 4 and 5). The models weighed from 350 to 1305 pounds. The first design was simply a hollow sphere to check Morris' correlation which relates small sphere data to larger spheres (refs. 1 and 2). The remaining designs represented a reactor surrounded by radiation shielding and a containment vessel, both of which were designed to absorb impact energy. The tests were conducted at the Sandia Sled Track in Albuquerque, New Mexico. They were impacted at speeds from 241 to 580 ft/sec. No leaks were detected nor cracks observed on any of the models after impact. Also, test data from the first impact test of the 24 inch diameter hollow vessel design verified that large vessels do deform like small vessels as predicted by the hollow vessel correlation derived from the 3/4 inch to 4 inch o.d. vessel data. This lent credibility that the data obtained on two foot model tests could be applied to the full scale reactor containment vessels which are of the order of 15 to 20 foot in diameter.

As a result of this program a new series of impact tests were planned to determine the effect on the containment vessel and reactor core of higher velocities, vessel welds, vessel penetrations, and type of impact surfaces. The models are similar to those formerly tested with an emphasis on different shield and containment vessel materials, and core and containment vessel designs. These models are designed and built at LeRC and tested at the Holloman Track, Alamogordo, New Mexico by the Kirtland Air Force Weapons Laboratory Albuquerque, New Mexico. Impact velocities in excess of 1000 ft/sec were planned. Post evaluation is conducted by both LeRC and the Air Force.

The first test model of this series of tests was impacted at 640 ft/sec (ref. 6). This report describes another test conducted at 1055 ft/sec. A description of the model, test set-up and results of the the test are presented. The model is being measured, sectioned and analyzed in detail at the Lewis Research Center but these results are not yet available.

DESCRIPTION OF SLED TEST

The impact test was conducted at the Holloman Track in Alamogordo, New Mexico. This is a dual rail track extending 35,588 feet. Only 2000 feet of the track was used for this test. The test set-up is shown schematically in figure 1. It consists of a pusher sled, payload sled, sled splitter and target. A bridge frame is placed over the track for mounting some of the cameras.

The model is placed on a "payload sled" (ref. fig. 2). It is attached by nylon straps which provide the support during sled operation. A "pusher sled" containing four Genie motors for its propulsion thrust pushes the "payload sled" down the track (ref. fig. 3). Having reached predesigned speed the "pusher sled" is stopped by water braking and momentum exchange. It is reused for additional tests. The "payload sled" continues down the track propelled by twelve Zuni motors staged six and six.

A "sled splitter" placed at the end of the track (ref. 4) is designed to separate the impact model from the "payload sled." This massive 22,000 pound structure is weld fabricated from 3 and 6 inch armor plate. Knives are positioned on the "sled splitter" to cut the nylon support straps and allow the impact model to pass through. The "payload sled" is destroyed with each test by the "sled splitter." Small shape charges are also placed on the "payload sled" to initiate its destruction.

Fifty feet beyond the "sled splitter" is a concrete block (ref. fig. 5) five foot on a side weighing approximately 18,000 pounds. The impact model having been separated from the "payload sled" continues a free flight impacting against the concrete block.

Three movie cameras are mounted at the impact point (ref. fig. 6, Fx 2, 3, and 4). They operated at speeds of 4545 and 9090 frames/sec. An additional camera was mounted on a bridge over the track looking toward the impact area (Fx 1). This camera operated at 4545 frames/sec. Its purpose was to record an overall view including secondary impacts. Additional movies were taken from a helicopter in real time and 250 frames/sec. showing the entire test sequence.

TEST MODEL

A drawing of the model tested is presented in figure 7. A photograph of it prior to impact is presented in figure 8. It consists of a reactor core mock-up surrounded by shielding and a two foot diameter spherical stainless steel containment vessel. The shielding consists of metal saddles (fig. 9) and rock salt. The metal saddles simulate an energy absorbing gamma shield. Rock salt simulating a LiH neutron shield material is poured into the 80 percent void spaces provided by the saddles.

The fabrication stages of the core and containment vessel are shown in figures 10(a) to (c). The simulated core consists of an 8-inch diameter by 8-inch long cylinder, 1/4 inch thick, filled with approximately 850 - 1/4 inch tubes of 0.065 inch wall thickness (fig. 10(b)). This assembly is capped on both ends and placed within a 12 inch diameter spherical stainless steel vessel 5/16 inch thick.

This assembly is then centered within a 5/8 inch thick two foot diameter containment vessel by small rods which are tack welded to the containment vessel and to the simulated reactor sphere (fig. 10(c)). The rods are weak and have no effect on the results of the impact test. Saddles and salt are added via the $1\frac{1}{2}$ inch pipe fitting after completion of the welding of the containment vessel.

The tubes in the model core simulate the fuel pins and flow passages of either a fast or thermal reactor core. The 12 inch containment vessel represents a gamma shielding material.

The total weight of this model was 1119 pounds (fig. 7). The core including tubes cylinder and one foot diameter sphere weighed 139 pounds. The saddles and salt weighed 450 and 180 pounds, respectively. The outside two foot diameter by 5/8 inch nominal wall thickness vessel weighed 350 pounds.

TEST RESULTS

The impact model was slung on the "payload sled" by nylon straps. It was oriented such that the pipe fitting was up-range from the impact point (fig. 2). In this position the impact did not occur on the weld, i.e., the weld was in a plane parallel to the face of the concrete block. The weld, however, was deformed due to the diametral increase of the model. This orientation also caused the impact forces to be applied to the mocked-up reactor core along its longitudinal axis. The direction of impact is shown in the drawing of the model of figure 7.

The rocket ignition point was at the 32850 foot track station. Impact of the sled with the "sled splitter" and subsequent release of the model occurred at the 34790 foot track station. The last speed recorded by the track sensors was 1023 ft/sec.

Upon impact of the sled with the "sled splitter" the model separated from the nylon sling and passed through the "sled splitter" impacting with the concrete block 50 feet beyond. In prior tests the concrete block was positioned only 25 feet beyond the "sled splitter" and the result was that the splitter was pushed back to the concrete due to the impact forces of the sled. The extra 25 feet, plus a trench half way between, prevented the sled from interfering with the impact sequence of the sphere and the concrete block.

Figure 5 shows the "sled splitter" and concrete block prior to impact. Shape charges on the "payload sled" intitiated destruction of the sled with the "sled splitter" prior to impact. The position of the splitter after the test is shown in figure 11. Little damage resulted to the splitter and it can be used for additional tests.

Impact velocity of the model with the concrete block, as measured by the high speed film was 1055 ft/sec. This is an increase in velocity of 32 ft/sec over that recorded just prior to impact of the sled with the "sled splitter." This increase velocity is due to the "sling shot" effect of the nylon strapping. The model is retained in the sled by two sets of straps.

Just prior to impact of the "sled splitter" with the "payload sled," the cutter on the splitter severs the first set of straps leaving the model momentarily suspended in the sled by the second set of straps which are still under tension. The model then is accelerated in the direction of motion by about 32 ft/sec. When the "payload sled" impacts the splitter the momentum of the model tears loose the second set of straps.

Figure 12(a) to (h) shows a consecutive sequence of photographs of the model at impact with the concrete block. These pictures were taken with camera Fx 3 (9090 frames/sec) in figure 6. During the impact the model disappears in a cloud of dust indicating that the concrete block is being pulverized during the impact.

After impact the model was found laying some distance away (about 50 ft) from the impacted concrete (see fig. 13). It had been deflected by the concrete and came to rest in the position shown. The concrete block suffered total destruction.

Photographs of the impacted model are shown in figures 14(a) to (c). Deformation occurred in both, the impacted hemisphere and the hemisphere opposite from the direction of impact. The hemispherical weld was not oriented perfectly in a plane parallel to the face of the concrete target. Consequently, the weld is closer in some areas to the deformation radius of the impacted face than the others. This results in a concave impacted face in the area where the weld is the closest. The reason for this is that the weld region is the thickest and therefore stronger than the adjacent material thus forcing the adjacent material to greater strains.

A leak test was performed on the model. This test consists of pressurizing the containment vessel to 50 psig with helium gas. The entire assembly is then encapsulated in a plastic bag; the interior of the bag is probed for leaks using a mass spectrometer type leak detector. No leaks were detected.

Measurements were taken of the sphere. These measurements indicate how much strain occurred. The maximum diameter occurred at the impacted face. It was measured as 29 inches compared to 24 inches prior to impact.

This is a diametral strain of 21 percent. It is of the same magnitude as similar impacted models (refs. 4 to 6). The amount of deformation δ/R was measured as 0.91 (where δ is defined as the diameter of the vessel before impact minus the height of the vessel after impact and R is the vessel radius before impact). The 0.91 value for δ/R is larger than those impacted models measured before. At higher impact velocities the diametral deformation also increased. The diametral deformation, however, did not show an increase comparable to the deformation δ/R. This probably was partly due to the weld restraining the diameter from growth. Distortion of the containment vessel in the nonimpacted hemisphere was transferred to the upper regions around the filler plug as shown in figure 10.

Further measurements will be taken to more accurately evaluate the deformation and strain that occurred on the unit. The model will be sectioned to evaluate the distortion that occurred on the core. Test specimens will be machined and tensile tests made.

CONCLUSIONS

This report presents data of an impact test against a reinforced concrete block of a 2-foot diameter mock-up model of a reactor containment vessel system. The test was conducted at the Holloman Test Track in Alamogordo, New Mexico. The model weighed 1119 pounds. It was impacted against an 18,000 pound concrete block at 1055 ft/sec. The following observations were made from the results of this test:

1. No leaks were detected nor cracks observed on the model.
2. The concrete block was totally destroyed at impact.
3. There was no rebound velocity observed when the model impacted the concrete block.
4. The maximum diametral increase measured on the model was 21 percent.

5. The deformation δ/R was measured as 0.91 (where δ is defined as the diameter of the vessel before impact minus the height of the vessel after impact and R is the vessel radius before impact).

6. The velocity of 1055 ft/sec for this test was the highest impact velocity that has been run to-date.

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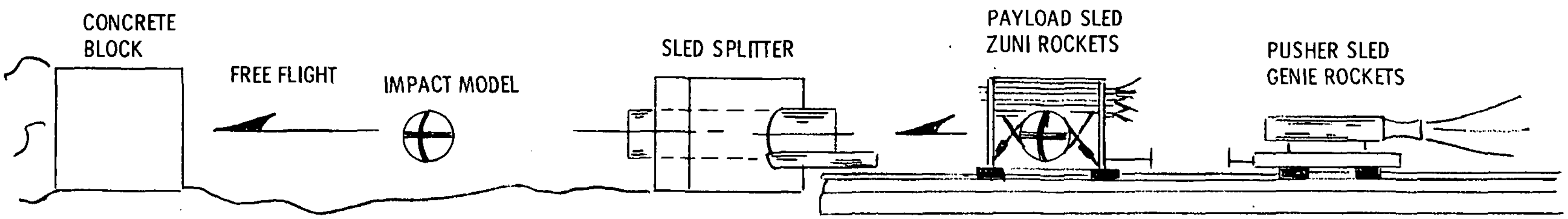

Figure 1. - Rocket sled test set-up.

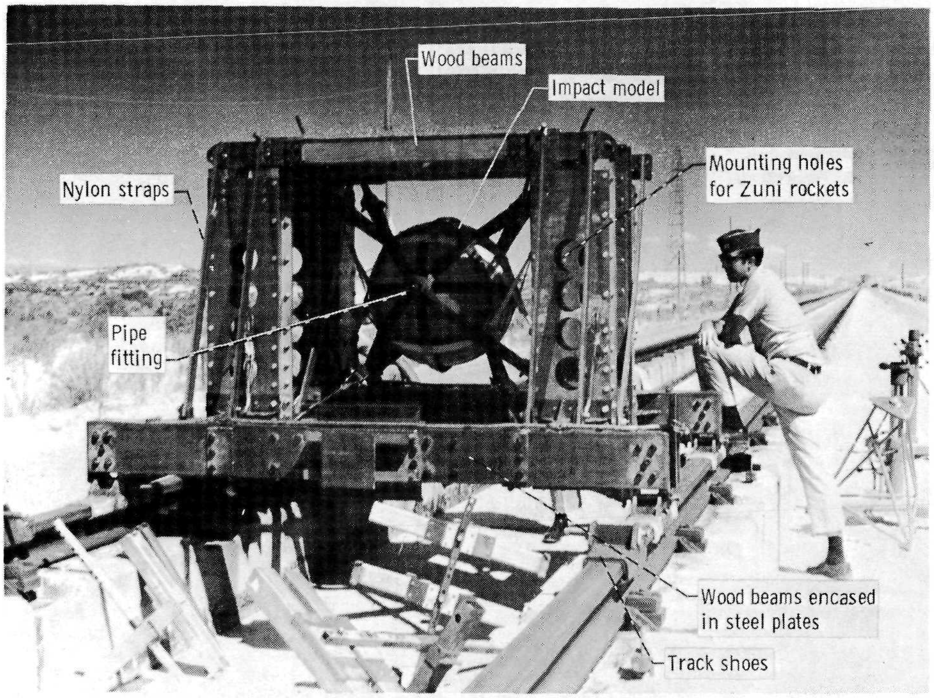

Figure 2. - Payload sled.

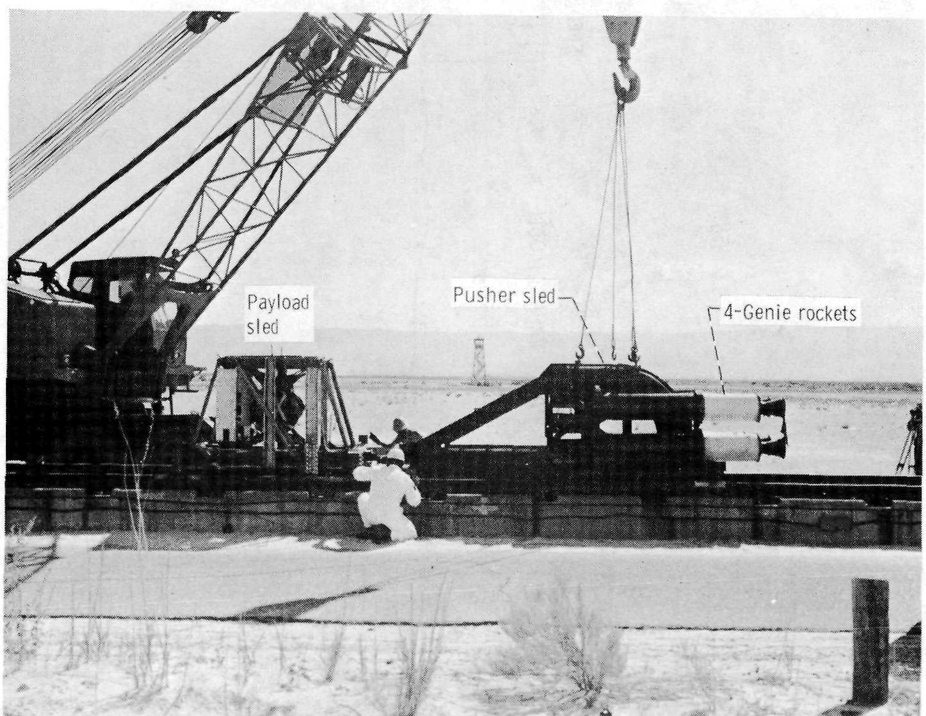

Figure 3. - Pusher sled.

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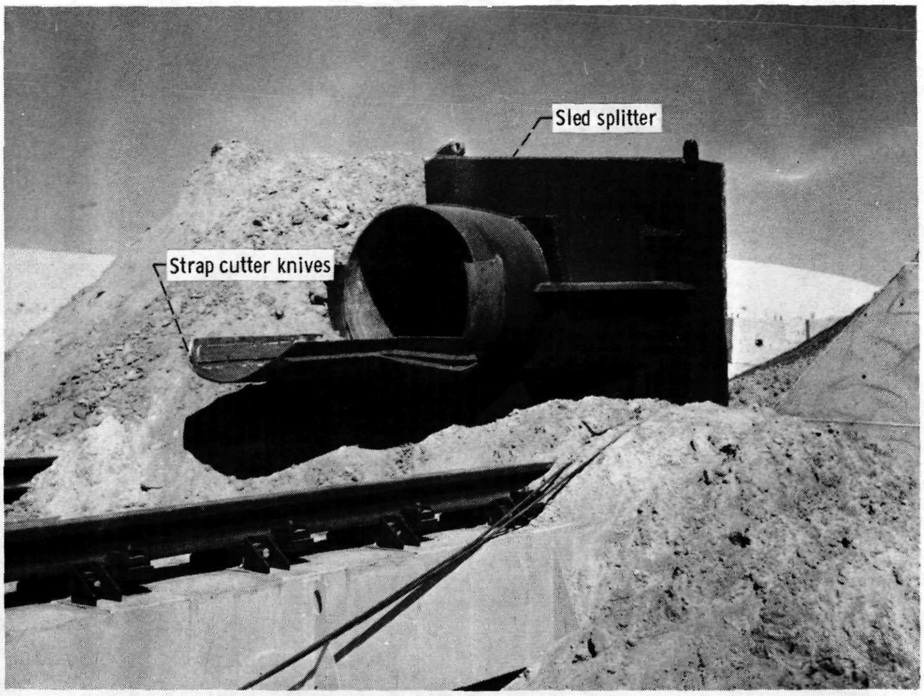

Figure 4. - Sled splitter at end of track.

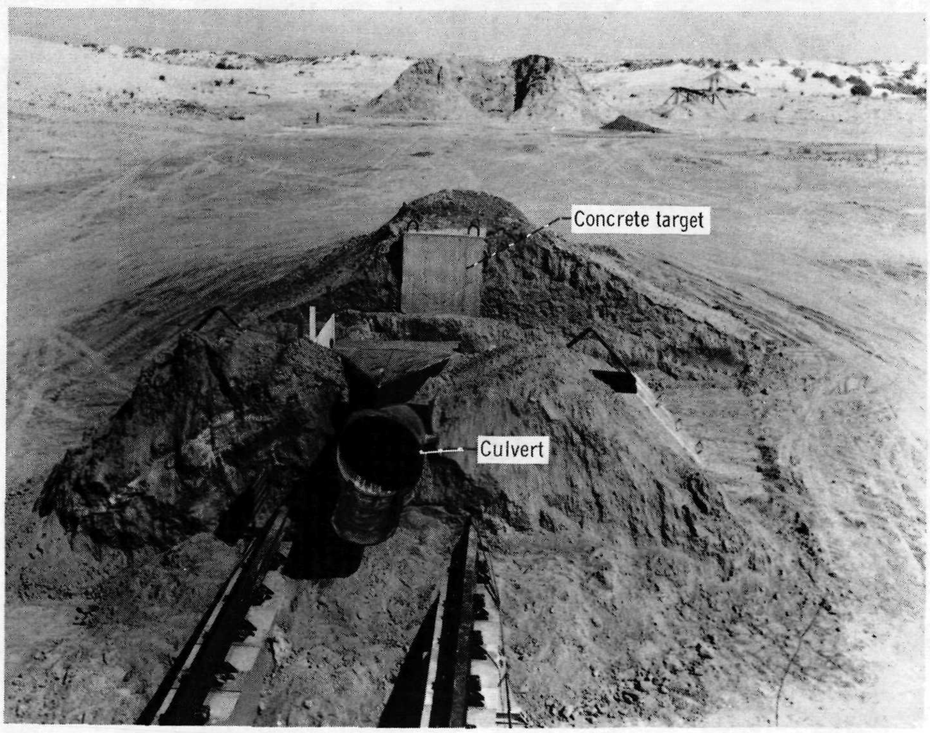

Figure 5. - Sled splitter and concrete target.

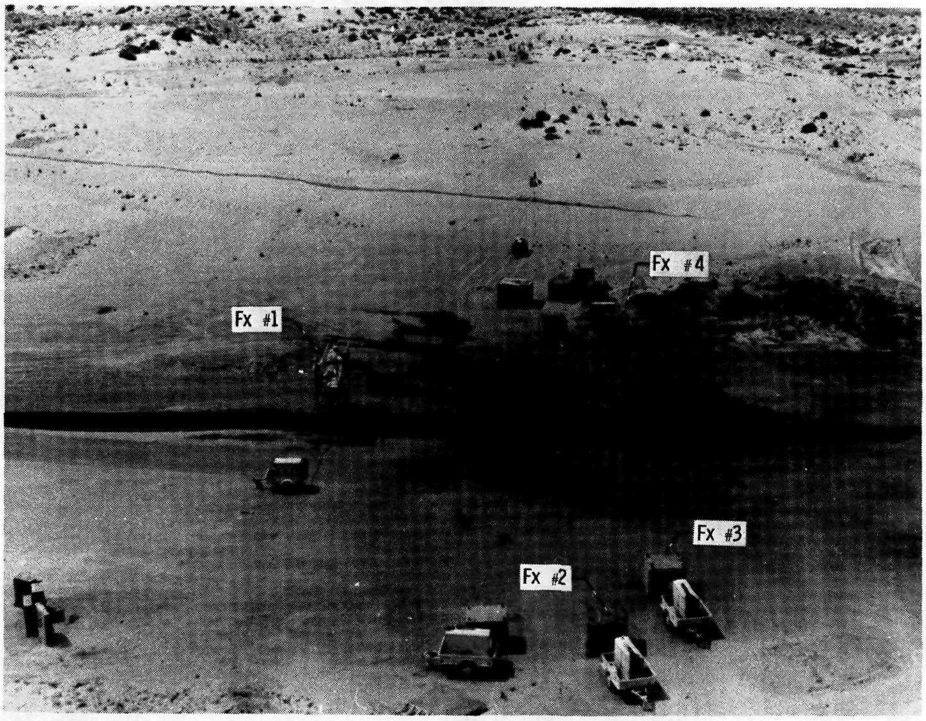

Figure 6. - Movie camera location.

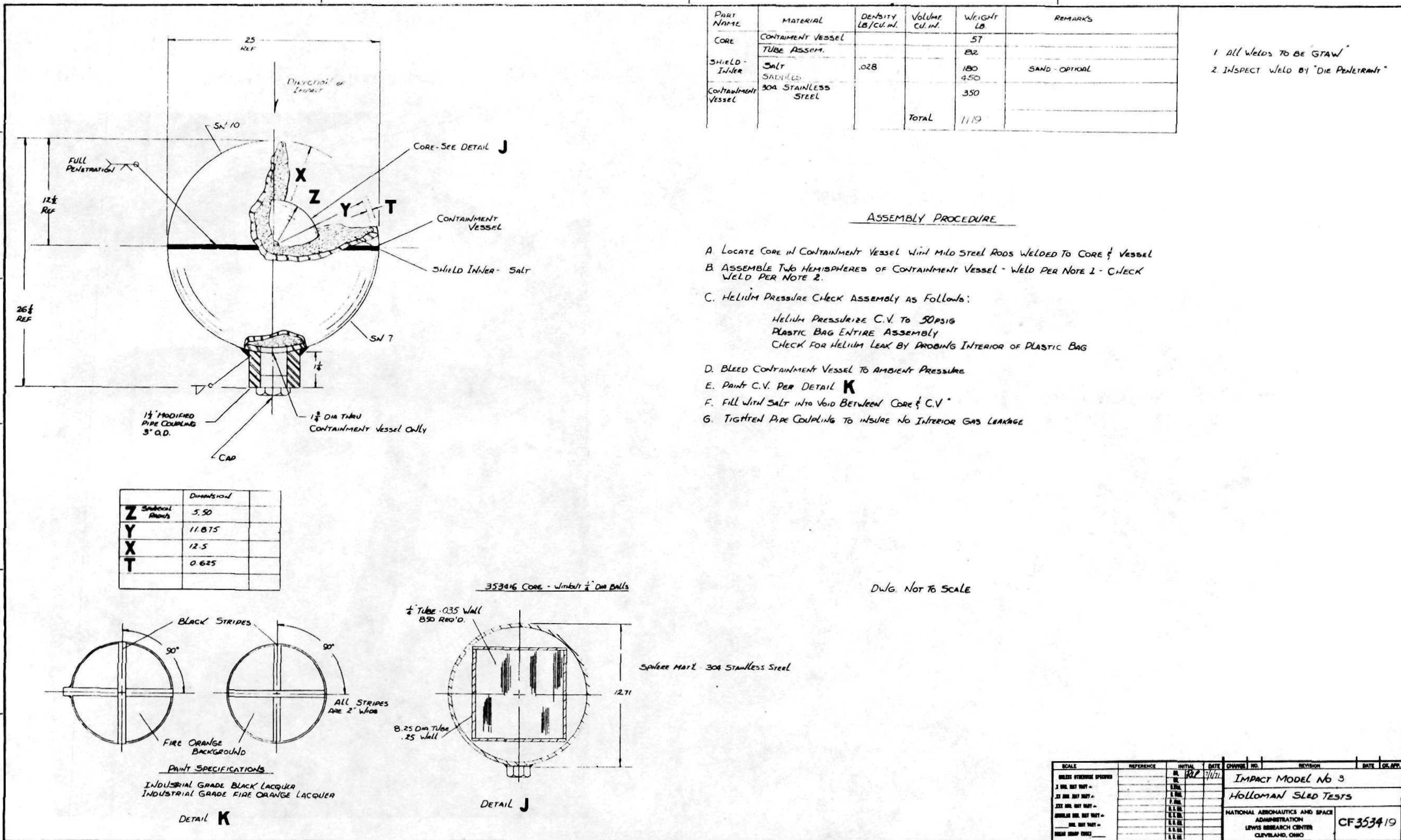

Figure 7. - Impact Model 353419 (#3).

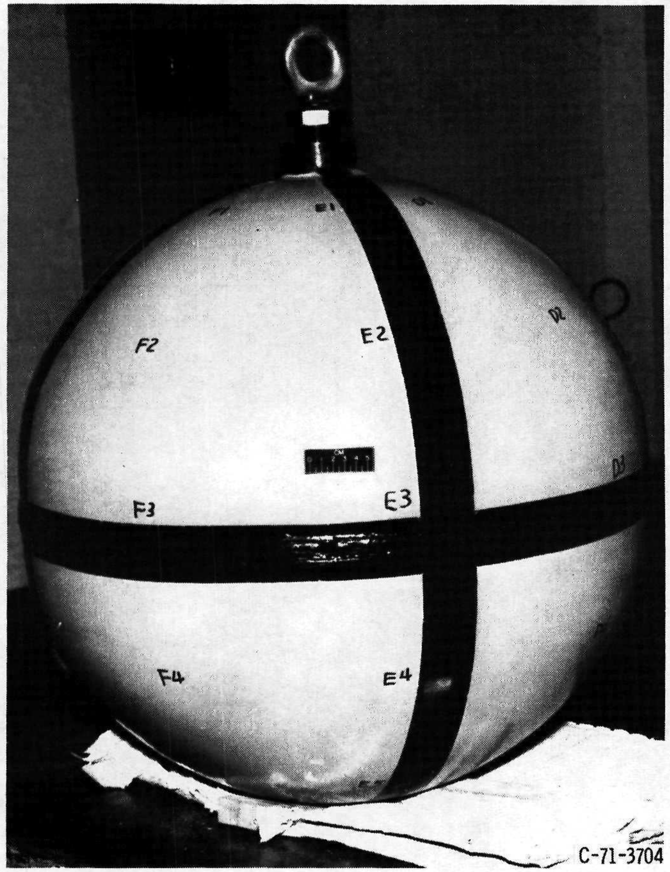

Figure 8. - Model prior to impact.

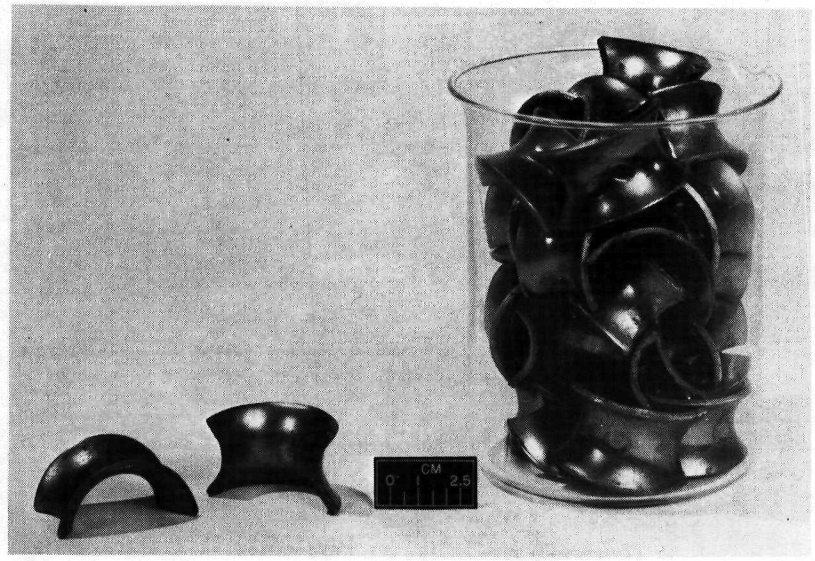

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Figure 9. - Steel saddles which simulate gamma shield material.

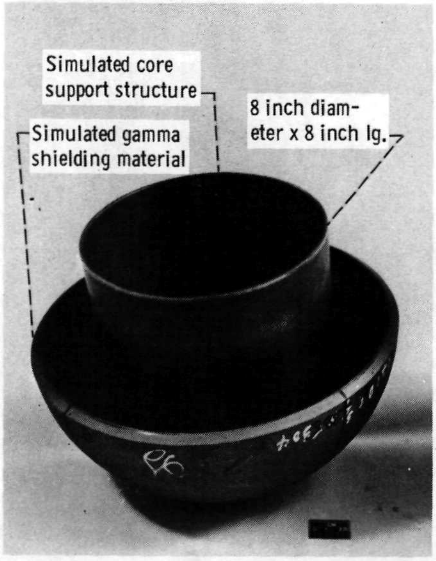

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Figure 10(a). - 8 inch diameter core cylinder welded into 12 inch diameter simulated gamma shielding material.

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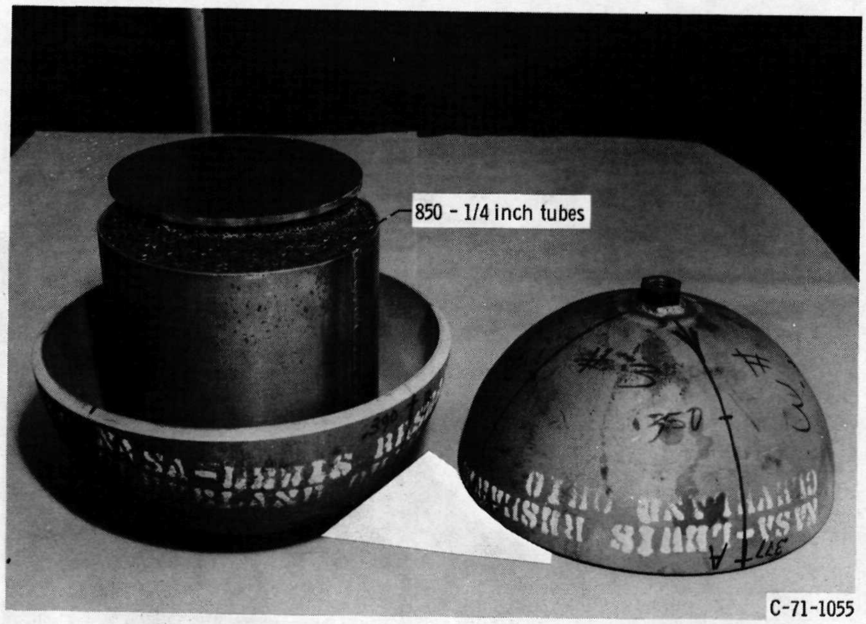

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Figure 10(b). - Core showing bundle of 850 tubes.

Figure 10(c). - Core centered in containment vessel.

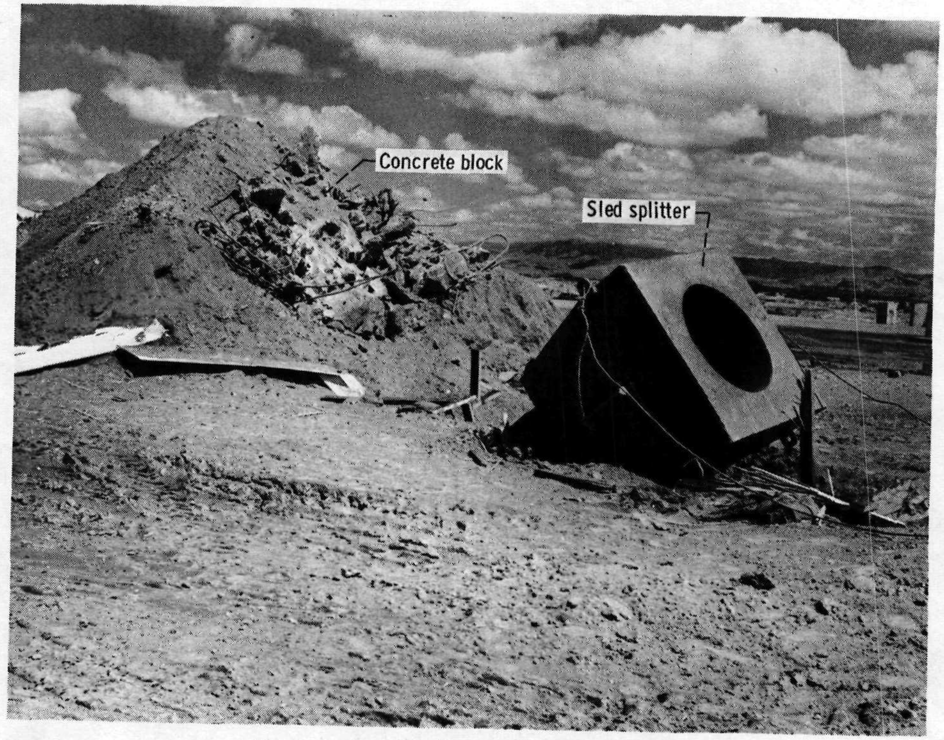

Figure 11. - Position of sled splitter after impact.

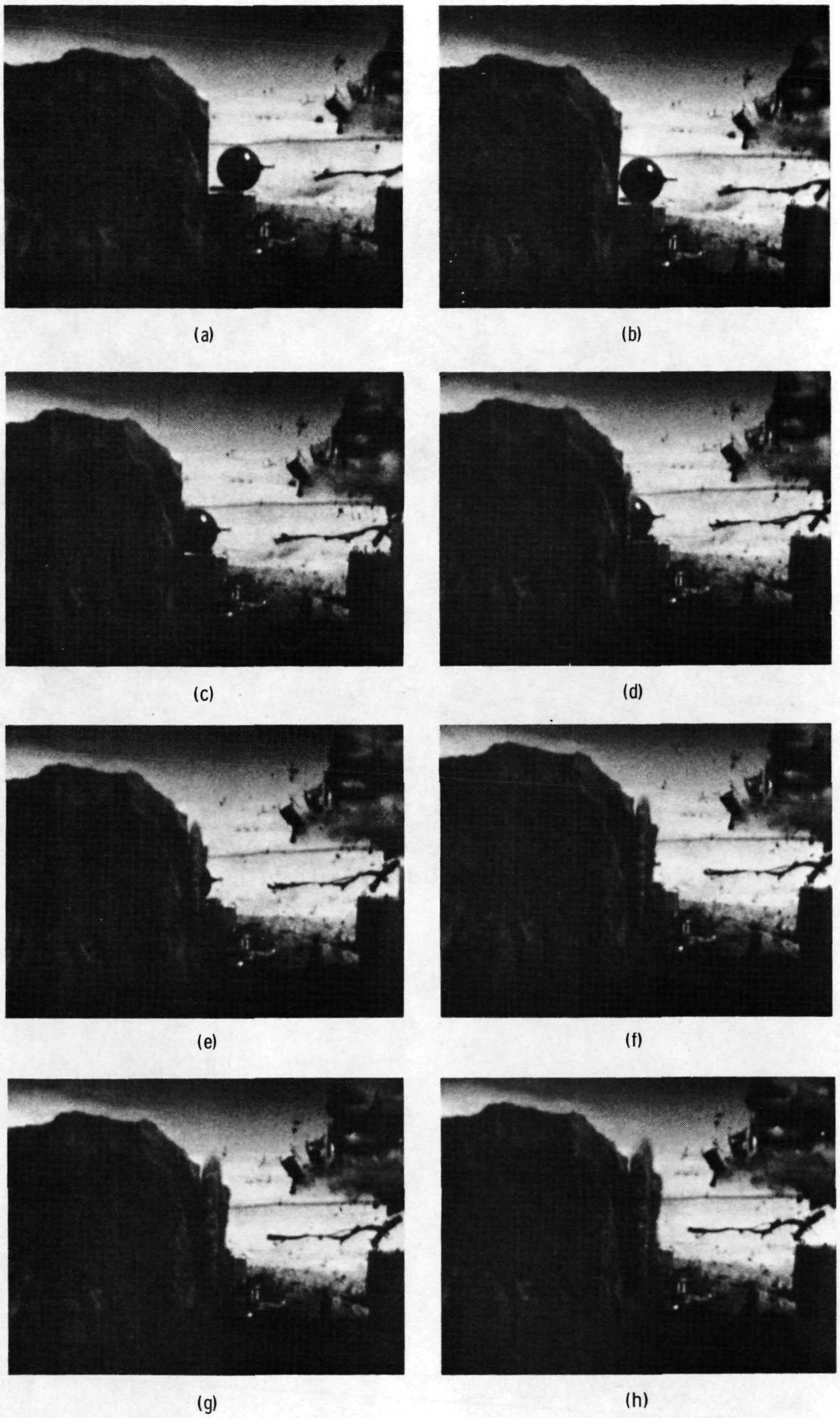

Figure 12(a-h). - Sequence photographs of impact. 9000 frames/sec.

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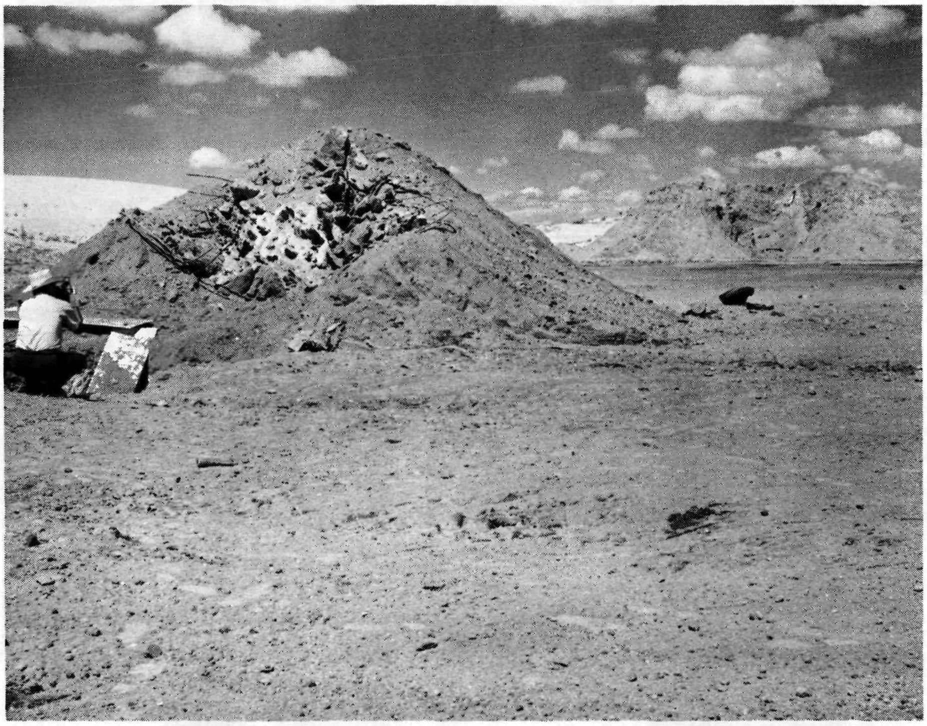

Figure 13. - Concrete target and model after impact.

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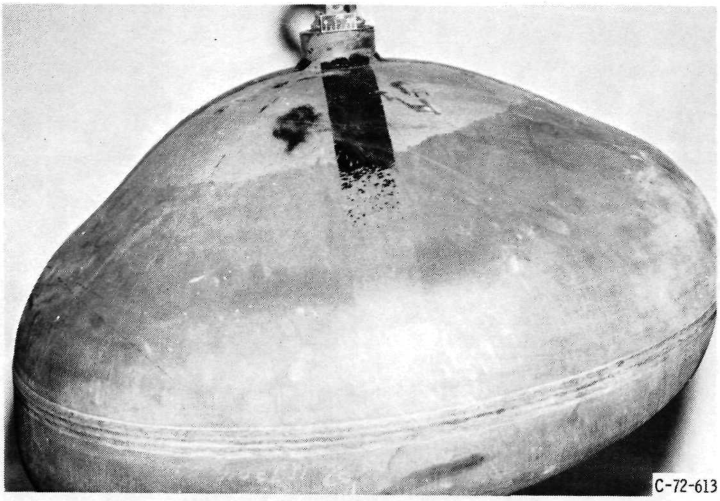
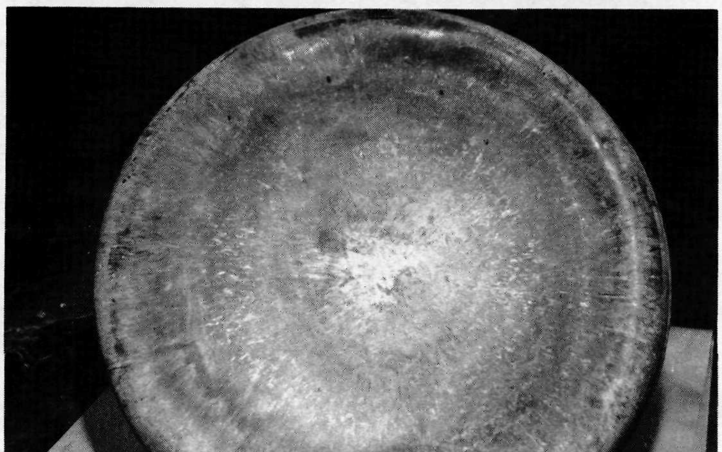


(a)

(b)



(c)

Figure 14. - Model - post impact.